WELL LOG INTERPRETATION OF THE CERRO PRIETO FIELD

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INTRODUCTION

The basic objective in geothermal well logging is the detection of moderate to high permeability zones containing high temperature fluids. Furthermore, identification of lithology and fluid composition will aid in regional mapping of the resource area.

Most geothermal systems are found in lithological units uncommon in petroleum exploration. To study complex lithologies, one needs calibration data which at the present time do not exist for many mineralogical units. For simpler systems, such as sedimentary type, conventional well logs may have some application.

Consider a sand-shale series type of sediments exposed to hydrothermal fluids. Because of exposure to high temperatures and as a consequence of rock-fluid interaction, the properties of the rock may undergo severe alterations. The degree of such alteration is dependent upon the rock permeability. The higher the permeability, the more surface area is available to the invading hydrothermal fluids. Thus, the nature of alteration in permeable sand is expected to be different than that in the shales.

Hydrothermal alteration may result in the formation of microfractures. It may change the chemistry of the cementation material and various metamorphic reactions may happen including dehydration and decarbonation.

To examine how these changes affect the well log responses in a sedimentary type geothermal field, we studied the well logs from the Cerro Prieto field in Mexico. A fair amount of well logs are available for the field. Copies of the logs were obtained through the Lawrence Berkeley Laboratory.

DESCRIPTION OF THE FIELD

The Cerro Prieto field is located on a plain in Mexicali Imperial rift valley, Fig. 1. It covers an area of 7400 acres. The installed capacity of the field is currently 150 MW and by 1985 plans are to boost the power output to 400 MW with the eventual goal of 1000 MW.

Among the many studies conducted on lithology, the one that relates closely to the subject of our discussion is the X-ray diffraction data published by Elders et al.[1] From their studies, indications are that in the hydrothermally altered zones clays are found in dehydrated form and considerable reduction in rock porosity may have happened.

METHOD OF STUDY

Because of nonexistence of high temperature tools, well logs were run in the field under a pre-cooled borehole condition. The most complete suite of logs available includes ϕ_{DC}, γ-ray, DIL, SP, CNL with occasional acoustic, dipmeter and temperature logs.

The behavior of interstitial clays was scrutinized on the well log responses. Observations made were related to clay composition. The onset depth of the hydrothermally altered zone was determined through a series of crossplots.

OBSERVATIONS AND DISCUSSION

One of the significant features of the conductivity logs is the sudden drop in electrical conductivity within the hydrothermally altered zones, Fig. 2. This drop coincides with an anomalous rise in the recorded SP, Fig. 3. Using a Waxman-Smit[2] type model to represent the behavior of shaly sands, the reduction in conductivity may be attributed to low salinity, loss of clay surface conduction, loss of porosity or a combination of the above.

Both core data and Compensated Density Log indicate reduction of porosity in the altered zones. This in turn is reflected in the increase in formation resistivity factor. Both LL8 and ILd reflect this phenomena, Fig. 4. However, the rate of increase in LL8 is much higher than the rate observed for ILd. This difference may be caused by the difference in composition between the mud filtrate and formation water. Since R_{mf} is generally higher than R_w, the difference in responce may be related to the surface conductivity effect. As it has been shown earlier,[3] at low salinities, surface conductivity has a greater impact on rock conductivity.

The increase in SP may be caused by several factors such as the streaming potential, high salinity, divalent cations, and the change in the nature of clay particles.

The alteration of clays in shales seems to be limited structurally and is evident as induration effect as seen from the ϕ_{CW} and ϕ_D responses. However, the hydrogen index for such zones seems relatively unchanged since ϕ_{CN} still reads higher than ϕ_D, Fig. 5.

For shaly sand the hydrogen index in shallow and unaltered zones is relatively significant, Fig. 6, while in altered zones a reversal of the two porosity curves occurs.

Unfortunately, in no case did we see evidence of 3 porosity logs for a given well. In rare instances where both acoustic and density log data are available, the evidence of micro-fractures may be seen from the difference in responses of the two tools.

Spiderweb diagrams prepared for the wells show recognizable patterns for altered and unaltered zones. Figures 7 and 8 are examples of such comparison.

Complete lithological analyses using the well log data is not currently possible because of insufficient data. The technique discussed in this paper, however, may be used to locate hydrothermally altered zones and construct structural maps of the reservoir.

ACKNOWLEDGMENT

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REFERENCES

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2. Waxman, M. H., and Thomas, E. C., "Electrical Conductivities in Shaly Sand - I. The Relation Between Hydrocarbon Saturation and Resistivity Index; II. The Temperature Coefficient of Electrical Conductivity," Journal of Pet. Tech. (Feb. 1974) p. 213.

3. Ucok, H., Temperature Dependence of Electrical Resistivity of Aqueous Salt Solutions and Solution-Saturated Porous Rocks, Ph.D. Dissertation, Univ. of So. Calif. (Dec. 1979).

Fig. 1. Location of the Cerro Prieto Field

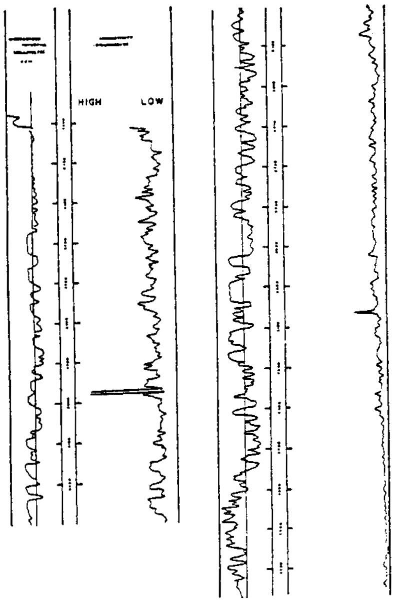

Fig. 2. Typical Conductivity Profile with Depth

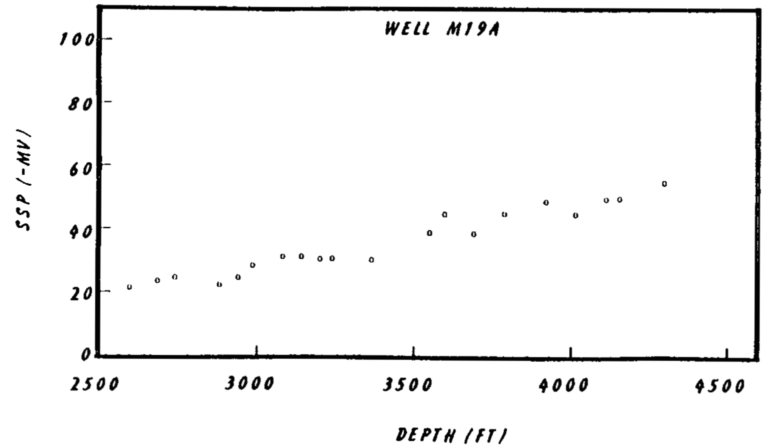

Fig. 3. Increase in SP with Depth

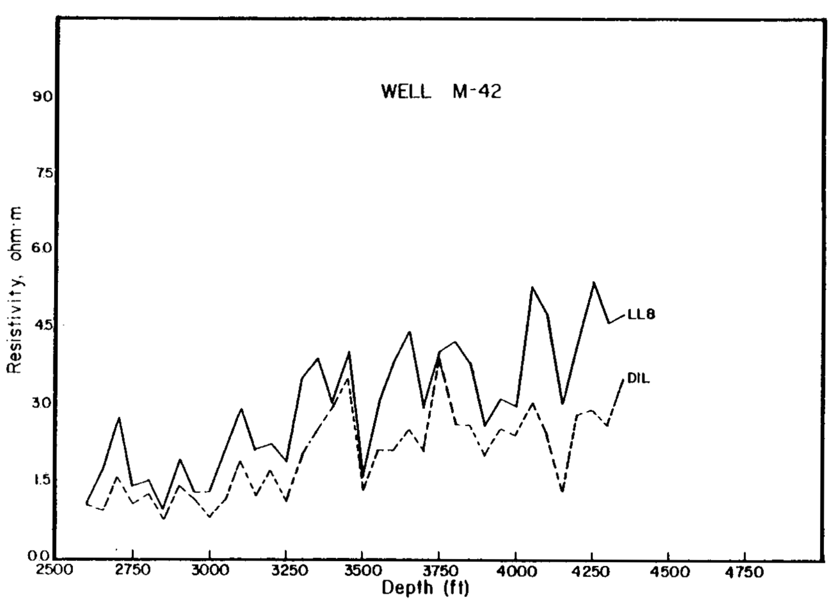

Fig. 4. Comparison of LL8 and DIL

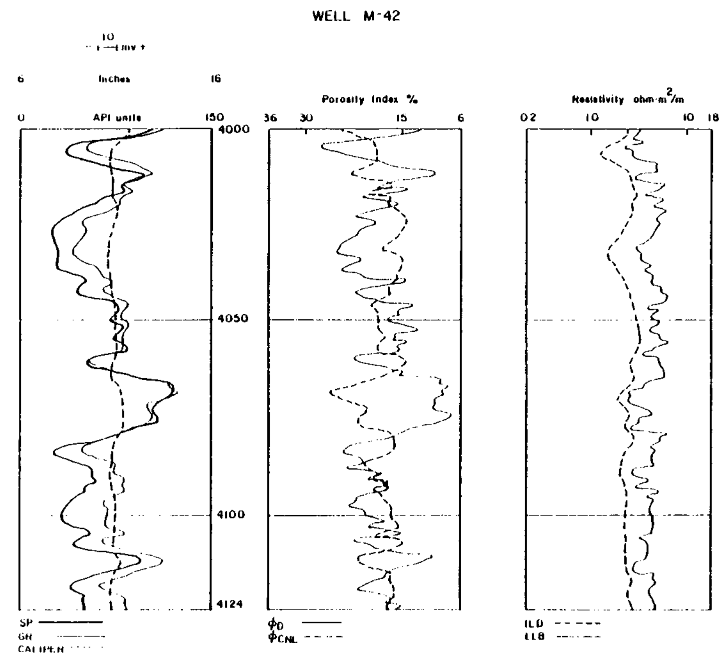

Fig. 5. ϕ_D vs. ϕ_{CNL} in an Altered Zone

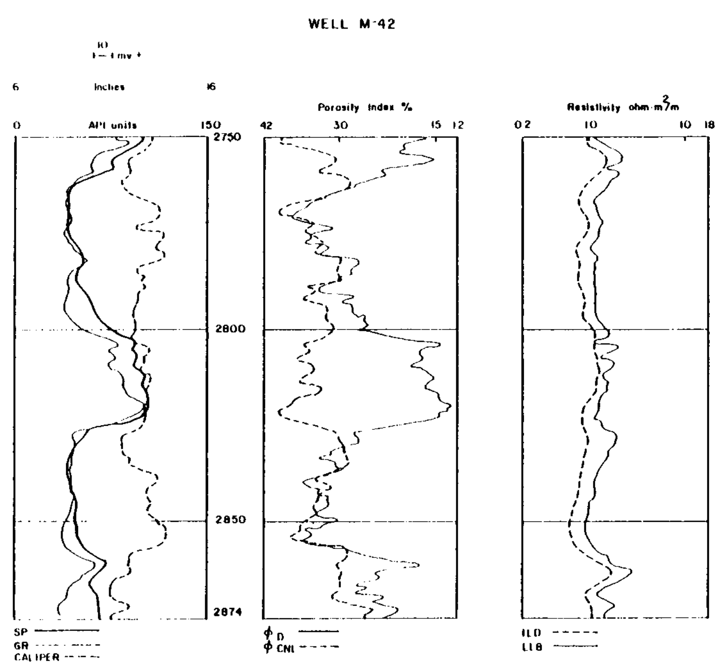

Fig. 6. ϕ_D vs. ϕ_{CNL} in an Unaltered Zone

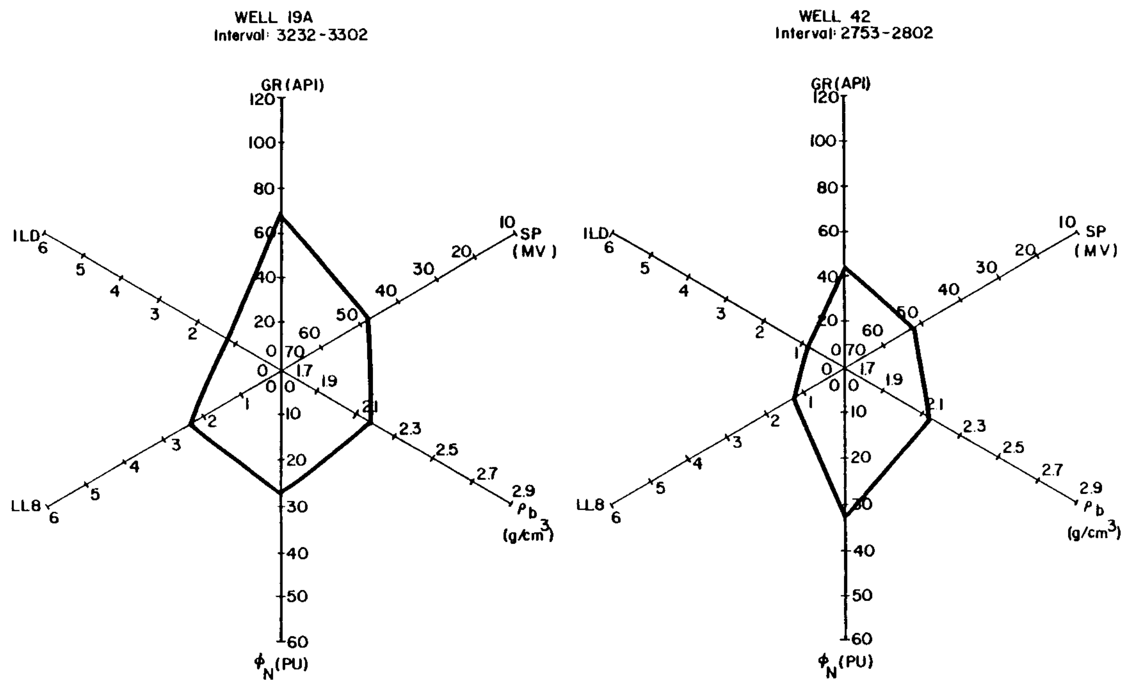

Fig. 7. Typical Spiderweb Diagram in Unaltered Zones

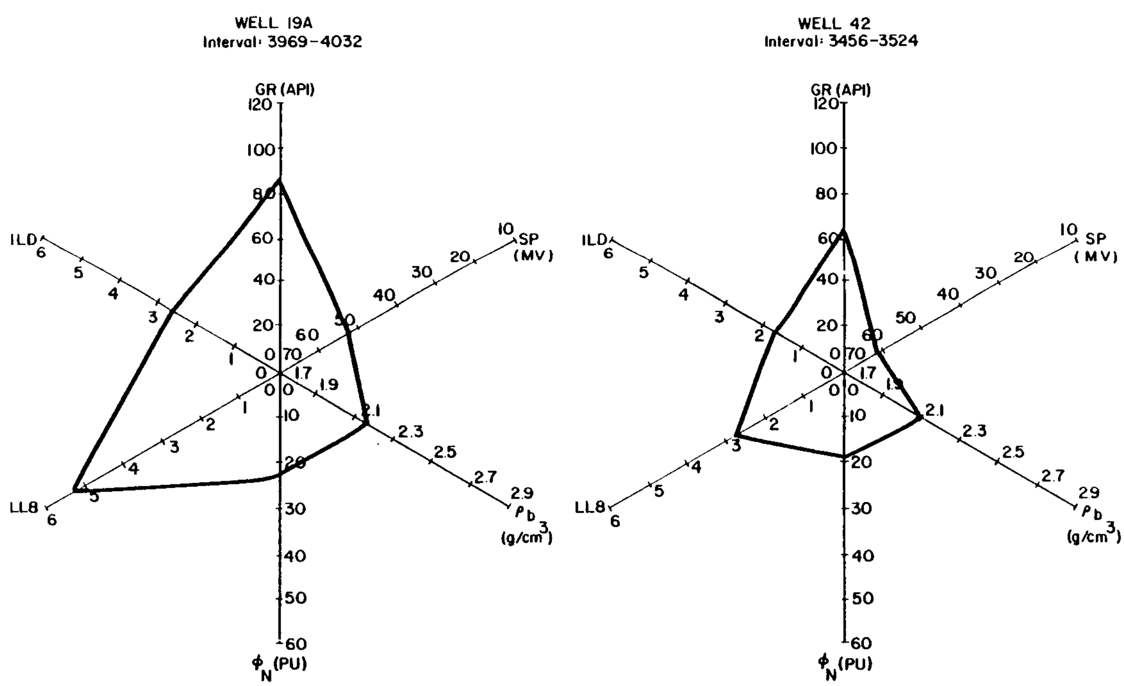

Fig. 8. Typical Spiderweb Diagrams in Altered Zones